DS2 Project: Drosophila suzukii ”Developing effective, economically viable and sustainable management strategies”

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Abstract

The DS2 project (2019-2022) evaluated several management methods for the pest *Drosophila suzukii* in cherry orchards and strawberry crops. A major study conducted on the trap plant *Pyracantha coccinea* showed strong potential in the laboratory but strong constraints during the first experiments in greenhouses. Management strategies based on the physical protection of cherry orchards by perimeter nets showed a potential in reducing phytosanitary interventions without causing side effects on crops. The development of the biological control method using exotic parasitoids was carried out through the identification of a species, *Ganaspis* cf. *brasiliensis* G1, very specific to the pest, promising trials in confined greenhouses and the finalization of an application file for the introduction of the parasitoid validated by the ministries. In addition, work to deepen our knowledge of the biology of the insect has led to a better understanding of the dynamics of fly populations and to complete the development of a model of egg-laying simulations that can be used as a decision-making tool to predict periods of risk on cherries.

Keywords: *Drosophilidae*, biological control, alternative method, integrated pest management, strawberry, cherry

1. Introduction

The spotted wing drosophila, *Drosophila suzukii* (*Diptera, Drosophilidae*) is a pest native to Asia, whose range has expanded spectacularly since 2008. It is currently present across a large part of the globe, in Europe, the United States and Latin America and now in South Africa (IPPC, 2024). Officially identified in France in 2010, it causes considerable damage to many fruit species, particularly cherries and small red fruits (strawberries, raspberries, blackberries, blueberries) but the species was also found in apple fruits (Deconninck *et al.*, 2024a). This drosophila has a high potential for causing damage. Unlike native Drosophila, its ovipositor is sclerotized and sawtooth-shaped (Atallah *et al.*, 2014). This feature enables it to lay eggs under the skin of fruits before they are ripe and therefore before they are harvested. In addition to cultivated fruit, larvae can also develop in a large number of wild fruits (Kenis *et al.*, 2016; Poyet *et al.*, 2015), including those of invasive plants (Poyet *et al.*, 2014) or those present in winter preceding the fruiting period of the earliest commercial crop fruits (Deconninck *et al.*, 2024b; Deconninck et al., in press).

This broad host range, combined with a short development cycle, means that populations can grow very rapidly. Moreover, *Drosophila suzukii* shows a great migration capacity between crop stands and semi-natural or anthropized habitats, using forest and hedgerows (Ulmer *et al.*, 2022, 2024), gardens (Deconninck *et al.*, 2024a) and even urban areas (Ulmer *et al.*, 2024) for shelter or to find alternative resources. These characteristics may explain the limitations of protection strategies. To meet the phytosanitary, environmental and economic challenges of protection against *D. suzukii*, the DS2: *Drosophila suzukii* "Developing effective, economically viable and sustainable management strategies" project has been implemented from 2019 to 2022 and financially supported by CASDAR funds. This project, led by CTIFL, brings together several partners: for research, INRAE PACA (Institut Sophia Agrobiotech, ISA), CNRS (Laboratoire de Biométrie et de Biologie Évolutive, LBBE), Université de Picardie Jules Verne - CNRS (Unité EDYSAN); for experimentation, CTIFL, APREL (Association provençale de recherche et expérimentation légumière), SudExpé, Domaine expérimental La Tapy ; for development, the Alpes Maritimes (06) Chamber of Agriculture and CRIIAM Sud (Centre de Ressource et d'Innovation pour l'Irrigation et l'AgroMétéorologie en région Sud); for technical and higher education, the EPLEFPA Louis Giraud agricultural college (now Provence Ventoux) and the Ministry: DRAAF SRAL PACA.

The aim of the project was to develop innovative methods that have so far been little explored in our region. These methods are :

- The reduction of *D. suzukii* population levels on a landscape scale, by developing a method of biological control by acclimatisation which would benefit all the crops affected;
- Reducing population levels at plot level by using peripheral nets, which could be a compromise to single-plant and single-row nets (which are effective but require considerable investment and a complete overhaul of the cropping system);
- Diverting ready-to-lay *D. suzukii* females away from crops by using trap plants to reduce insect pressure in crops under cover.

These methods have also been combined with other protection methods, such as prophylaxis or chemical strategies, to identify strategies that are economical in the use of plant protection products, and whose effectiveness and technical and economic benefits have been assessed. A decision-making tool has been developed and made available to growers so that strategies can be implemented in advance of risk periods, i.e. egg-laying periods. The two model crops used in these studies are strawberries for crops grown under cover, and cherries for arboriculture and open fields.

2. The use of trap plants: evaluation in the laboratory and in the field

The great polyphagy of *D. suzukii is an* advantage for the insect as it provides it with a large number of resources and temporal continuity (Lee *et al.*, 2015; Kenis *et al.*, 2016; Poyet *et al.*, 2014, 2015; Ulmer *et al.*, 2022; Deconninck *et al.*, 2024a). However, polyphagy has a cost and can lead *D. suzukii to* make oviposition errors, i.e. to lay its eggs in plant fruits that are unsuitable for larval development and in which the larvae end up dying (Poyet *et al.*, 2015; Ulmer *et al.*, 2020). Such plants that lure and deceive *D. suzukii* are known as trap plants. This environmentally sustainable method has already been validated for other crop pests (Lin *et al.*, 2006).

In the project, the effectiveness of trap plants as an innovative and ecologically acceptable method for reducing *D. suzukii* infestations of strawberries *was* tested in the laboratory by the CNRS EDYSAN unit and in the greenhouse by CTIFL and APREL. The trap plant studied was chosen from 67 previously tested species (Poyet *et al.*, 2015) based on various criteria: a high oviposition rate with a very low Drosophila emergence rate; presence in France; availability in horticulture; resistance and ease of maintenance; and the plant's perennial life form (shrub). The trap plant chosen was *Pyracantha coccinea*, the slow-growing shrub (Ulmer *et al.*, 2020).

2.1. A promising trap plant in the laboratory

Cultivated fruit and fruit from trap plants were placed in competition for the oviposition choices of *D. suzukii*, by placing these plants in the greenhouse systems. Oviposition rates and larval development in the different fruits were observed.

In the laboratory, five *D. suzukii* (three females and two males) were offered a choice test between a strawberry and a corymb of *Pyracantha* for 24 hours in a phytotron. The control consisted of just one strawberry with the same number of flies for the same length of time. This test showed that in the presence of Pyracantha, the number of adult *D. suzukii* emerging from the strawberries was reduced by 47%. In addition, no flies emerged from all the eggs laid in the *Pyracantha* fruit.

The second test evaluated the effect of distance, 5 or 30 cm, on the choice of *D. suzukii* between a strawberry and a corymb of *Pyracantha*. For each modality, the fruit was exposed to five *D. suzukii* (three females and two males) for 24 hours in a phytotron. Increasing the distance between the two types of fruit had no influence on the choice of Drosophila egg-laying medium (Figure 1a): *Pyracantha* showed a significantly higher infestation whatever its distance from the strawberry. For both modalities, the number of eggs laid on the *Pyracantha* corymb was much greater than the number of eggs laid in the strawberry.

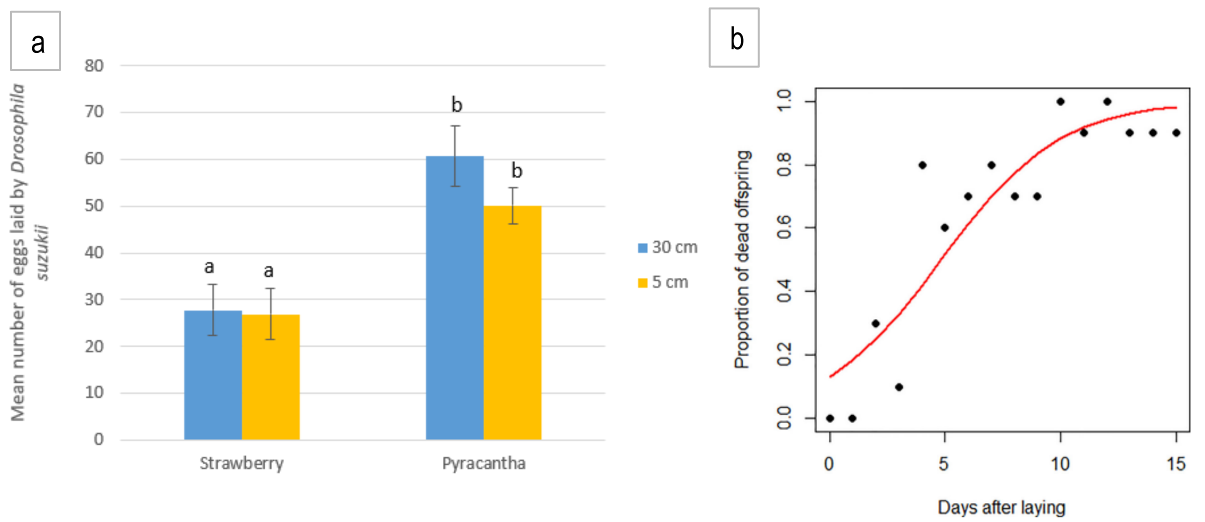

Figure 1: a) Number of eggs laid by *Drosophila suzukii* (three females and two males per test) on each species of fruit (1 strawberry versus a corymb of *Pyracantha coccinea* fruits) separated by 5 cm and 30 cm. Different letters

indicate a significant difference at p >0.05 between conditions and b) Proportion of dead *Drosophila suzukii* individuals observed in *Pyracantha coccinea* fruit as a function of the number of days after oviposition (adapted from Ulmer *et al.*, 2020)..

One hypothesis put forward to explain *D. suzukii*'s preference for *Pyracantha* fruit relates to the architecture of the trap plant's corymbs. The corymb is larger and has a more complex architecture than a strawberry, with numerous small branches that could provide a refuge in which the drosophila could hide and which could increase the attractiveness of its fruit.

A mini-greenhouse trial was set up to assess the attractiveness of the trap plant under conditions closer to the field. For this set-up, four potted strawberry plants, each bearing two red strawberries, were placed alone in a control mini-greenhouse, and for the mini-greenhouse testing the trap plant, *Pyracantha* branches bearing fruit and leaves were planted in plots and added to the set-up. In both modalities, the plants were exposed to 25 *D. suzukii* (15 females and 10 males) for 72 hours. For each mini-greenhouse, the eight strawberries and 100 *Pyracantha* fruits were kept until emergence in order to quantify the *D. suzukii* infestation. This test showed that in the presence of *Pyracantha*, the number of adult *D. suzukii* emerging from the strawberries was reduced by 39%. In addition, none of the eggs laid in *Pyracantha* fruit produced adult flies.

A trial to study the survival of *D. suzukii* offspring in the trap plant was also carried out to gain a better understanding of the stage of development at which individuals die. To do this, four *Pyracantha* fruit clusters were placed in contact with five *D. suzukii* females each for 24 hours. Each day for a fortnight, the fruit was dissected to observe the development stage and survival of 10 eggs and/or larvae. This trial showed that almost all the eggs hatched (only 2 out of 150 did not hatch) but after five days, almost 50% of the individuals had died, and after ten days almost 100% of the *D. suzukii* individuals had died (Figure 1b). No larvae reached the pupa stage and all showed signs of browning.

2.2. Further research is needed to adapt the method to greenhouse crops.

Trials were then carried out in an experimental greenhouse to assess the selected trap plant, under conditions closer to those encountered in practice.

An initial study was carried out on an above-ground strawberry crop in the experimental greenhouses at the CTIFL. The crop was planted in August 2020. This late planting means that fruiting of the strawberry plants coincides with that of the *Pyracantha* plants to maximise the trapping effect. The young *Pyracantha* trap plants were grown in pots and placed under and at the end of the crop rows, at a density of 0.25 trap plants/m² (i.e. 2,500 plants/ha). Three greenhouse compartments were equipped with *Pyracantha* plants and two control compartments received no trap plant. When the first red strawberry fruit appeared, 30 female and 20 male of *D. suzukii* were added to ensure that the pest infested the 5 test compartments evenly and sufficiently. The fruit was then harvested, 80 fruits per compartment, twice a week, for four weeks.

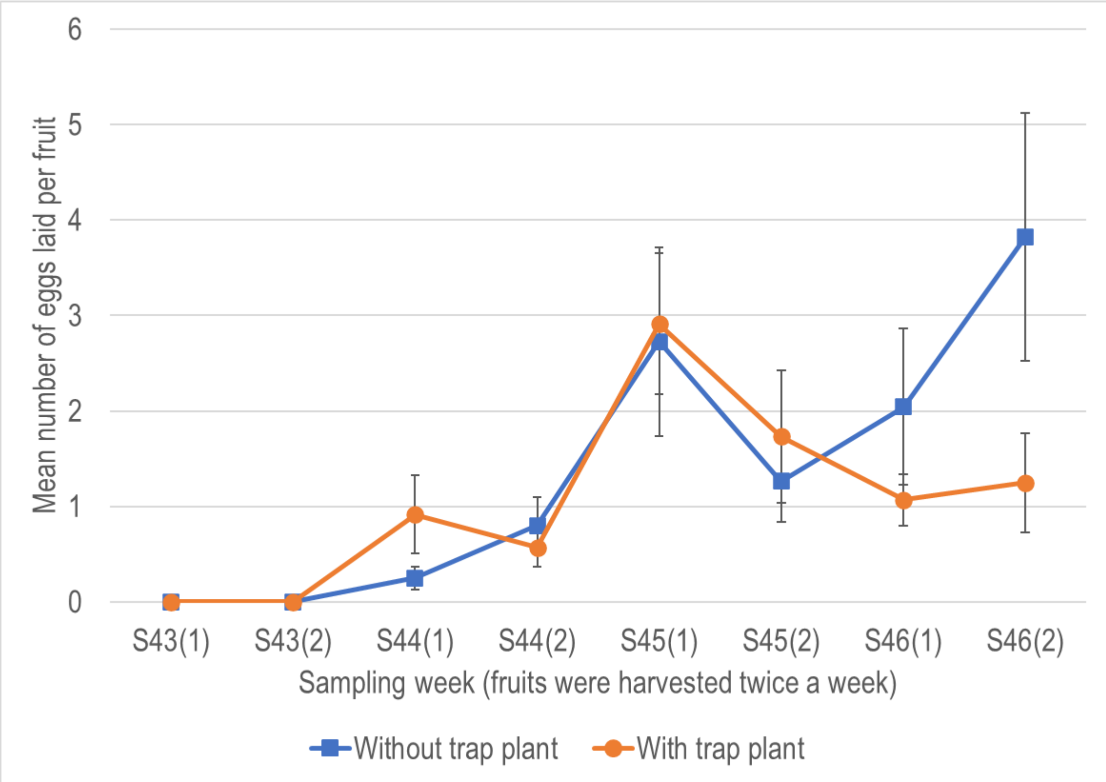

Figure 2: Average rate of infestation of strawberries by *Drosophila suzukii* eggs for the control (no trap plant) and trap plant treatments, observed at each harvest date between weeks 43 and 46 of 2020, twice a week. The error bars represent the standard error.

Over the trial period, the average rate of infestation of fruit by larvae was not significantly different between the control and the treatment with *Pyracantha* plants (p=0.729). The same was true for the average infestation rate of *D. suzukii* eggs observed in the fruit (p=0.210). From week 45 onwards, the average infestation rate fell in the trapping plant treatment. A date-by-date analysis did not reveal any significant difference between the treatments in terms of the average infestation rate in the fruit, for either larvae or eggs, with the exception of the last harvest date (S46(2)) (Figure 2). At the last measurement, the number of eggs per fruit was significantly lower in the treatment with trap plant than in the control (Kruskal-Wallis, p=0.004). Although the same trend was observed for the number of larvae per fruit, the difference was not significant at the 5% threshold (Kruskal-Wallis, p=0.13).

A second study was carried out by APREL on a strawberry grower's Mara des Bois everbearing variety, which is highly susceptible to attack by *D. suzukii*. The crop was grown in soilless conditions and the *Pyracantha* plants were placed under the crop rows so as not to impede traffic in the rows, at a density of 150 plants/ha. The APREL results did not show any effectiveness in reducing *D. suzukii* damage. The fruit infestation rate was equivalent between the tunnels with trap plants and the control tunnels without trap plant.

3. Physical control using perimeter nets and a combination of strategies

A structure based on peripheral netting, which is less expensive than a complete net and can be easily adapted to orchards that have already been set up and run in gobelet style, has been evaluated between 2019 and 2021 as part of the DS2 project. Nets of 4 m high were installed around the edges of three cherry orchards in Carpentras (Domaine expérimental La Tapy), Saint-Gilles (SudExpé) and Bellegarde (CTIFL Balandran) over a three-year period. Population levels are compared in the protected plots and in the controls, using the reference trapping method of the experimental network. Various aspects of the nets were assessed: their level of protection (used alone or combined with chemical strategies), their potential secondary effects (microclimate, phenology, beneficials and pests) and their technical and economic benefits.

The effectiveness of perimeter net alone varies from site to site and from year to year. When no insecticide treatment is carried out when the net is closed to "clean" the orchard, the fruit flies may become trapped inside, and the desired effect of blocking the entry of fruit flies into the plot is then null. On the other hand, if a single treatment is carried out when the net is closed, after flowering and pollinator activity over the two years of the trial, the 'net only' method at the SudExpé site is 66% more effective than the untreated, net-free control. This is still not enough to protect the crop adequately (more than 20% *D. suzukii* damage in 2020). Although this structure does not prevent *D. suzukii* from entering the plot, it does reduce the infestation (-61% of captures observed inside the net). This effectiveness was not found on the other sites, where frost or low pest pressure on the controls meant that some of the trials could not be validated.

In the actual context of increasing bans on molecules, and therefore on plant protection specialities, the perimeter net was also evaluated in combination with other protection methods in order to study the possibility of reducing the number of plant protection treatments compared with the reference strategy involving four treatments. A significant reduction in damage was observed in 2021 at the SudExpé site when two treatments were applied 18 days (lambda-cyhalothrin) and 5 days (cyantraniliprole) before harvest, in addition to the one applied when the net was closed 37 days before harvest. On the first harvest pass, the "net + 2 treatments" method was 74% more effective than the untreated control without net; on the second harvest, efficacy was 98% (see Figure 3) and on the last pass 83%. Compared with the "2 treatments without net" method, the " 2 treatments with net" method was 44% effective on the first harvest, 95% effective on the second harvest and 73% effective on the last harvest.

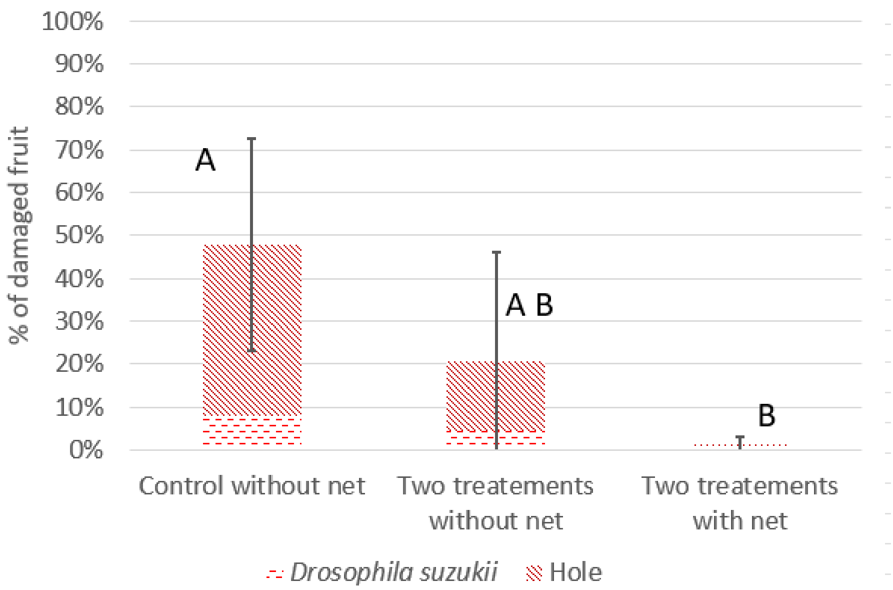

Figure 3: Fruit damage observed during the second harvest of Noire de Meched, on 15 June 2021, at the SudExpé site. Different letters indicate a significant difference at p >0.05 between conditions.

At the La Tapy site, the use of perimeter net did not improve the effectiveness of this light phytosanitary strategy in 2021. 1.10% of fruit was bitten outside the net and 1.40% inside the net, compared with 46.90% damage in the untreated control. On this site, the results are similar to 2019. The simple or light phytosanitary strategy did not show any increase in effectiveness due to the perimeter net (22% to 34% of fruit bitten on the treated strategy compared with 77% to 80% on the untreated controls).

At the CTIFL site, at the first harvest, the method with net and 3 treatments 14 (lambda-cyhalothrin), 7 (cyantraniliprole) and 3 days (spinetoram) before harvest was 92% more effective than the untreated control without net, and 83% more effective in the second harvest. Damages in the untreated control did not exceed 7%.

The installation of probes inside and outside the perimeter net during the three years of trials and on all the study sites did not reveal any impact of the net on the plot environment in terms of temperature or humidity (minimum, average and maximum). Similarly, the monitoring of phenological stages over the three years did not reveal any difference in the vegetative development of the trees following the installation of the net.

4. The development of classical biological control: from the integrative characterisation of exotic parasitoids in the laboratory and greenhouse to experimental introductions in the field

Most of these *D. suzukii* host plants are non-cultivated species that are spontaneously present and abundant at different times of the year (Kenis *et al.*, 2016; Poyet *et al.*, 2015; Ulmer et *al.*, 2022) including invasive plant species (Poyet *et al.*, 2014). They can therefore act as reservoirs and/or refuges for *D. suzukii* and are at the root of infestations observed in crops (Tait *et al.*, 2021). Managing populations of this pest in uncultivated areas therefore appears to be a key element in implementing an effective and sustainable integrated management strategy.

Among the alternative methods evaluated against this pest in the DS2 project, work continued on classical biological control by the introduction-acclimatization of exotic parasitoids. Previous projects have made it possible, through surveys in Asia in 2015 and 2016, to import several populations of exotic *D. suzukii* parasitoids (Girod *et al.*, 2018a) belonging to the genera *Asobara* (*Hymenoptera, Braconidae*), *Ganaspis* and *Leptopilina* (*Hymenoptera, Figitidae*) into quarantine laboratories (CABI in Switzerland and INRAE in France). At this stage, studies have consisted in characterizing certain biological traits of interest (host specificity in particular) and to specify the identity of the imported beneficials.

4.1 *Ganaspis* cf. *brasiliensis* G1: the most specific parasitoid

Parasitoid specificity tests in quarantine laboratory were carried out under no-choice condition, i.e. in the presence of *D. suzukii* only, and under choice condition, i.e. in the presence of several hosts including *D. suzukii.* In the latter case, various species of drosophila more or less phylogenetically related to *D. suzukii* were proposed: *D. melanogaster*, *D. subobscura*, *D. busckii*, *D. hydei* and *D. immigrans. Ceratitis capitata* (*Tephritidae*) was also tested because, although it is not a drosophila, it shares certain ecological requirements with *D. suzukii* for oviposition in fresh fruit. The results obtained showed that species of the genus *Asobara* and *Leptopilina* (including *L. japonica*) are capable of developing in several non-target *Drosophila* species, unlike populations of *Ganaspis* which develop almost exclusively on *D. suzukii* (Borowiec *et al.*, 2021 a).

In addition to this more restricted host spectrum, certain *Ganaspis* populations, including *G.* cf. *brasiliensis* G1 in particular, seem to share ecological characteristics with *D. suzukii*, namely development in fresh fruit only (Girod *et al.*, 2018 b and c). Trials conducted in a confined greenhouses at CTIFL have also confirmed the ability of certain *Ganaspis* populations (*G.* cf. *brasiliensis* G1) to parasitise *D. suzukii* directly on strawberry plants under production conditions and to induce a significant reduction on population development. In fact, *D. suzukii* populations were reduced by 35% to 46% in modalities with the introduction of parasitoids at compared with the control without parasitoids (Figure 4) (Gard *et al.*, 2021).

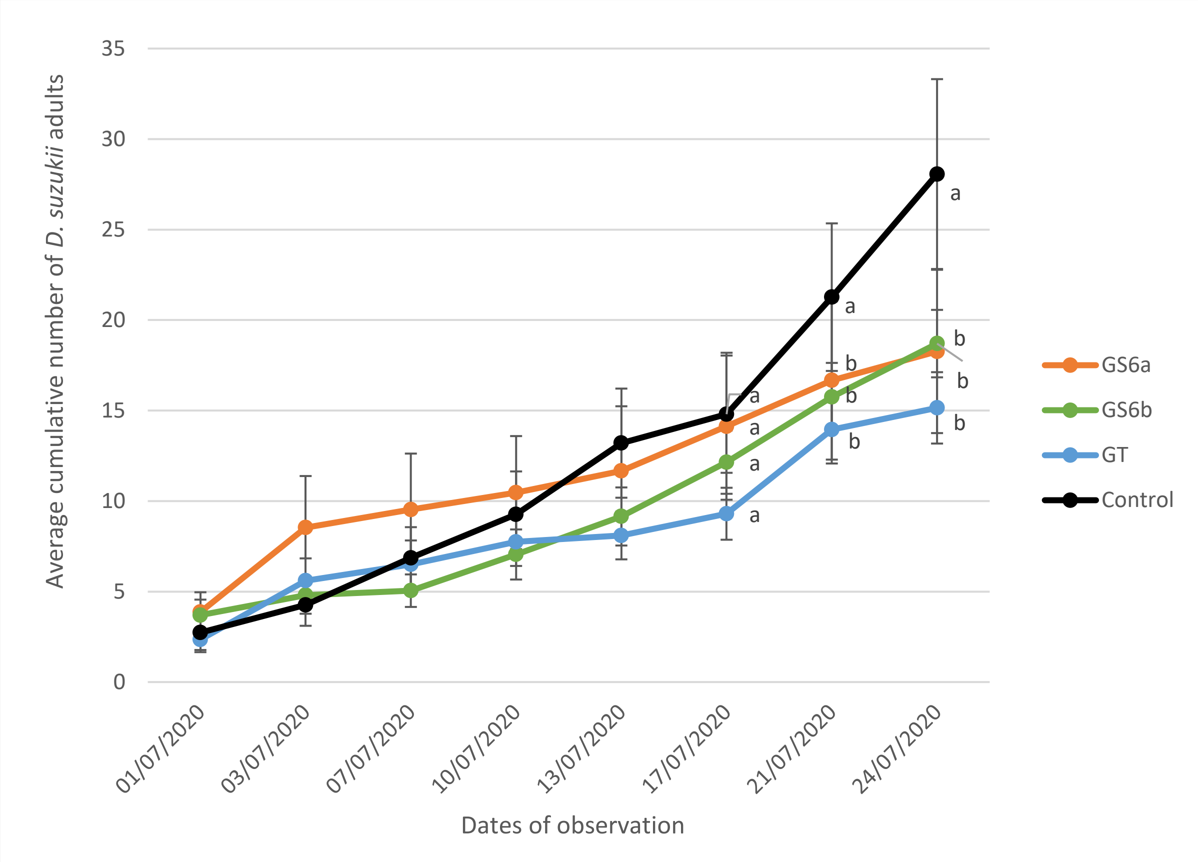

Figure 4: Trend in the number of *D. suzukii* adults emerging per strawberry harvested. The codes GS6 and GT correspond to the names of the sampling sites of the G1 population of *Ganaspis* cf. *brasiliensis,* and allow the two strains of the parasitoid to be identified. The error bars represent the standard error. Different letters indicate statistically different groups at the same date.

4.2 Reliable identification required before any introduction

To clarify the identity of the imported parasitoids, the different populations studied were subjected to molecular characterisation using several molecular markers (mitochondrial or nuclear). The results confirmed the taxonomic uncertainties observed elsewhere in the species named *Ganaspis brasiliensis* (Nomano *et al.*, 2017; Giorgini *et al.*, 2019), with the existence of several genetically differentiated clusters, one of which, group 1, brings together the most specific populations of *D. suzukii* (Seehausen *et al.*, 2020). Cross-breeding experiments carried out between individuals belonging to these different groups have also shown the existence of reproductive incompatibilities between certain groups, confirming the presence of different species within this complex. For example, individuals belonging to two populations (China and Japan) in group 1 are perfectly capable of reproducing, whereas crosses between individuals belonging to different groups (1 and 3, for example) have not produced any female offspring. These species reproduce arrhenotocally, meaning that female offspring are produced from fertilised eggs. Populations of *Ganaspis* cf. *brasiliensis* G1, i.e. belonging to molecular group 1, have therefore been identified as the most promising candidates for biological control of *D. suzukii* in several countries (USA, France, Italy, Switzerland).

5. Better knowledge of the insect to improve the *D. suzukii* model, *a* new decision-making tool

5.1. Impact of temperature on the fecundity of *D. suzukii*

Temperature is the main factor responsible for the distribution, dynamics and seasonal phenology of populations. In 2021, a CNRS-LBBE/DRAAF/CTIFL collaboration aimed to study, under controlled conditions, the effect of a rise or fall in temperature on Drosophila fecundity and to measure its response time.

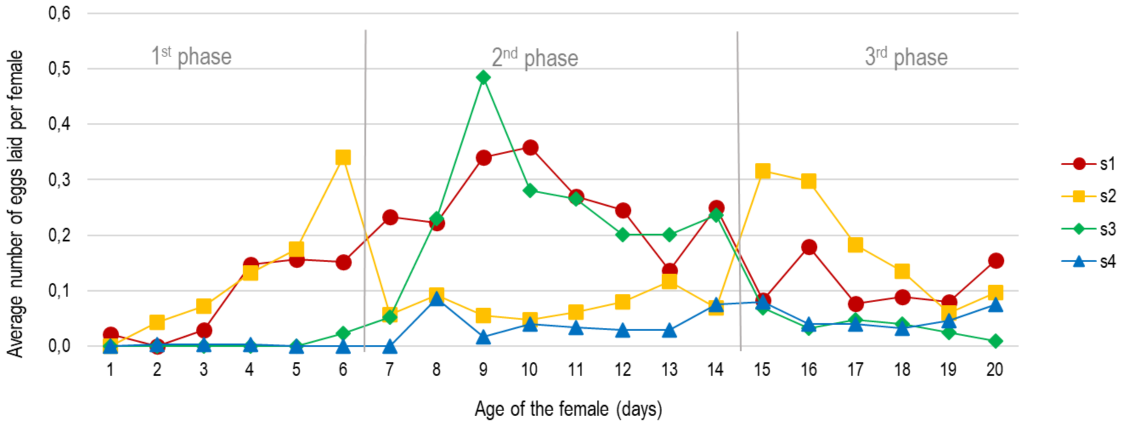

Figure 5: Changes in average fecundity per female over 20 days - Average number of eggs laid per female as a function of 4 temperature change scenarios over time. S1: 22°C for 20 days of trials; S2: 22°C for 6 days then 14°C for 8 days and finally 22°C for 6 days; S3: 14°C for 6 days then 22°C for 8 days and finally 14°C for 6 days; S4: 14°C for 20 days of trials.

The impact of 'temperature' on fertility was tested by varying the temperature between two contrasting values, 14°C and 22°C, and using a constant humidity of 70%. Four scenarios were played out, with or without alternating temperatures over identical time intervals. In the first scenario, the temperature was maintained at a constant 22°C for the 20 days of testing. In the second scenario, after six days, the temperature is lowered to 14°C and maintained at this temperature for eight days, before being raised again to 22°C. In the third scenario, the temperature is lowered to 14°C on the first day, held at this temperature for six days, then raised to 22°C for eight days and then lowered again to 14°C for six days. In the fourth scenario, the temperature is lowered to 14°C on the first day and maintained at this temperature for the 20-day test.

Laboratory results show that reducing the temperature from 22°C to 14°C has a significant negative effect on *D. suzukii* fecundity. When the temperature drops, conditions become unfavourable and egg-laying stops. They resume immediately when conditions become favourable again, i.e. when the temperature rises (Figure 5, scenario 2).

The results of the temperature test seem to indicate an immediate or almost immediate response to egg-laying by *D. suzukii*, i.e. within three days. These data are used to adjust the "*Drosophila suzukii*" simulation model.

5.2. The *Drosophila suzukii* simulation model

A "*Drosophila suzukii"* simulation model has been produced by the DRAAF PACA for cherries. It is not reliable for other crops such as strawberries or small fruit, which arrive later in the season. It simulates the population dynamics of *D. suzukii* at the end of winter as a function of temperature and humidity. This model is based on an original use of raw rearing data obtained under constant controlled conditions and published by colleagues at the USDA[1] (Tochen *et al.*, 2014 and 2016).

Temperature is the main factor influencing the speed of development, while hygrometry is the main factor influencing the insect's survival rate. The model simulates the arrival of a more or less intense egg-laying 'wave' and compares the years, without taking into account the 'stock' at the end of winter. The output of the model is a curve representing the daily oviposition dynamics of *D. suzukii* with a theoretical number of eggs over a given period. To compare several years, the simulations can be run one after the other, year by year. The numerical results of the simulations can be exported and reassembled.

To validate these simulations, egg-laying observations were made on cherries during the 2020 and 2021 seasons. The monitoring carried out at CTIFL is in line with the model simulations. Feedback from the field from the various partners in the DS2 project has enabled the model to be compared with reality and confirmed its suitability for use as a decision-making tool. This tool complements all the information available (history of the plot, winter conditions, etc.) when deciding on the protection strategy to implement in an orchard. The model has been made available in the PACA region via CRIIAM Sud. The rest of mainland France is covered by the CTIFL's Inoki platform.

6. Discussion

The trap plant *P. coccinea* was found to be effective in diverting *D. suzukii* females away from strawberries in laboratory tests and reducing the rate of oviposition in the fruit. These results were not repeated in the greenhouse trials. There are several possible explanations for this lack of effectiveness: the use of young, immature bushes with very little fruit, and the density of bushes in the glasshouses. In the laboratory trials, the number of Pyracantha fruits far exceeded the number of strawberries, which was not the case in the greenhouse trials. In addition, the management of the trap plants under cover was difficult: the presence of thorns meant that the shrub had to be pruned regularly and the late fruiting of the trap plant, not before the end of August, only offered potential protection during the last months of production of the remontant varieties. These trials are only preliminary laboratory tests and a long-term study, in the field and using much more mature Pyracantha shrubs at least three or four years old, would be necessary to validate the *in situ* effectiveness of the trap plant, before its use in a production system. Other systems need to be evaluated, such as installing trap plants in hedgerows bordering crops in an attempt to reduce *D. suzukii* pressure on farms. As part of the DS2 project, additional research has been initiated to determine whether larval mortality in fruit is due to the presence of toxic compounds, by studying chemical compounds in fruit to identify families of compounds with toxic effects; but this complex study needs to be extended.

Trials on perimeter netting produced contrasting results depending of the trial site. From a technical point of view, there are also a number of points to be borne in mind: the need for regular maintenance of the structure (grass management, stitching if there are any holes) and its positioning in relation to hedges, which can encourage pests to enter if they are too close to the net and higher than it. From an economic point of view, the investment costs of a net structure depend on the characteristics chosen: number of poles, type of fixings, type of door, labour for installation, etc. (Royer, 2022). In the project, this method was evaluated on small plots (< 4000 m²), and a larger-scale experimentation is essential to confirm these results.

The development of a biological control method is a medium- and long-term process involving a large number of stages. All the data produced in the project has been used to draft an application for the introduction into the environment of the exotic parasitoid *Ganaspis* cf. *brasiliensis* G1, including an assessment of the risks and benefits associated with these introductions (Borowiec *et al.*, 2021 b). After favourable assessments by expert committees (including Anses), in August 2022 INRAE obtained

[1] *United States Department of* Agriculture

authorisation, in the form of a joint order from the French Ministries of Agriculture and the Environment, to introduce this parasitoid into France for the purposes of biological control by acclimatisation. This represents a major step forward. This biological control operation by acclimatisation must now continue with the first introductions and the first monitoring of establishment in France in 2023. This work will be carried out as part of the SUZoCARPO Ecophyto project (coordinated by INRAE, 2023-2026).

The decision-support tool is an egg-laying simulation model that is destined to be improved in the light of advances in knowledge of the biology of *D. suzukii*. When it was designed, essential working hypotheses were incorporated into the model to take into account the reaction times of Drosophila to variations in temperature and hygrometry. The temperature fluctuation trial and the response of *D. suzukii* to these variations enabled us to improve the model and create a second version. However, as the trial was carried out in 2021, the modifications could not be made until late in the project, and this new version is still being validated by monitoring in the field.

7. Conclusion

The DS2 project follows on from the *Drosophila suzukii* project carried out from 2013 to 2016. It has enabled us to gain a deeper biological understanding of the pest's fecundity, refine the model used to predict oviposition risk periods and thus provide cherry growers with a decision-making tool. A major advance was made in the development of biological control by identifying an exotic parasitoid specific to *D. suzukii*, testing its ability to regulate the pest under glass and helping to obtain authorisation for the introduction of *Ganaspis* cf. *brasiliensis* G1 to continue the research. The work carried out on the trap plant *Pyracantha coccinea* showed promising results in the laboratory but was unsatisfactory during the initial greenhouse experiments. Areas for improvement in the use of this method have been identified and may be worked on in the future. Evaluation of the effectiveness of perimeter net around cherry orchards showed that this lever cannot be used alone. It remains an avenue to be explored to offset the disappearance of chemical specialities dedicated to managing the pest, with interesting results obtained by combining different levers. Combinations of methods to achieve reliable protection strategies under production conditions could only be assessed in the final year of the project. At this stage, they are not sufficiently robust. These are preliminary data that will form the basis for the forthcoming studies in the following projects: i) Occitanie Region and Agence de l'eau "Study and development of alternative strategies for combating flies (*D. suzukii, R. cerasi)* in cherry orchards *"* (CEFEL coordination, 2021-24), ii) action 9 of the PAUPFL emergency plan "Mouches des Cerises - Biocontrôle, Attract et kill, et Parasitoïdes" (CTIFL coordination, 2023-2026) and iii) Casdar STRATOS (CTIFL coordination, 2024-2027).

The results of the project were disseminated throughout the three years by means of articles in the specialist press and scientific journals, technical meetings, conferences and trial visits. A summary of the results was published (Fevrier *et al.*, 2023) and the various data and presentations of the results are available online on the project website: https ://drosophila-suzukii.ctifl.fr/ . The *D. suzukii* day organised at the end of the project was a great success, with over 120 participants (February, 2022). This event highlighted the mobilisation of the fields of research and experimentation to meet the challenge posed by *D. suzukii.*

Ethics
The authors declare that the experiments were carried out in compliance with the applicable national regulations.

Declaration on the availability of data and models
The data supporting the results presented in this article are available on request from the author of the article.

Declaration on Generative Artificial Intelligence and Artificial Intelligence Assisted Technologies in the Drafting Process.
The authors used artificial intelligence in the translation process from French to English.

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Declaration of interest
The authors declare that they do not work for, advise, own shares in, or receive funds from any organisation that could benefit from this article, and declare no affiliation other than those listed at the beginning of the article.

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